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Waste Plastic Recycling Information Exchange
Volume I. Summary Report

Monsanto Research Corp.
Dayton, OH

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Washington, D.C. 20460

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PREFACE

The Quality of Life

In November 1969, Foreign Ministers of the North Atlantic Council established the Committee on the Challenges of Modern Society (CCMS). They instructed CCMS to address the concern of the industrial nations for quality of life in this final third of the twentieth century. They directed CCMS to improve in every practical way the exchange among the allied countries of views and experience in creating a better environment for their societies. The overriding objective was to stimulate government action by members of the alliance.

The Pilot Study Approach

The working methods of the CCMS are based on three concepts, namely, a pilot country, orientation toward action, and open publicity. The pilot-country idea stemmed from the need to release the NATO international staff from the extensive tasks normally connected with implementing a multilateral venture. The CCMS entrusts the pilot country that has proposed a project with the responsibility for carrying it out. This includes planning the study, preparing necessary reports, and the subsequent action necessary for its realization. National leadership of the study permits international cooperative efforts to move ahead more quickly and efficiently than under the committee approach characteristic of most such work.

The action-orientation concept is reflected in the CCMS aim that studies be finished as soon as possible and recommendations be produced for a positive course of action by member countries and other international organizations. The CCMS has no intention of remaining actively involved in projects for 5 or 10 years. The purpose of CCMS is to catalyze collaboration on solving problems

of international concern. It was intended that CCMS should be involved in particular projects for perhaps 2 years, at which time the conclusions and recommendations from the study would be endorsed by CCMS and passed on to other forums for action and implementation.

The third concept, that of open publicity, is a completely new departure for NATO. The aim is to make information on the work of the CCMS widely available. The CCMS meetings are open to the press and to any intergovernmental organization wishing to send observers. The meetings of experts are also open to participants from any country or international body.

This Study

A pilot study on "Plastics Wastes" was approved November 1978 and an effort initiated by a group of experts in June 1979. The pilot-country was the United States and the pilot study leader was Carl J. Schafer (Director, Industrial and Extractive Processes Division, Office of Research and Development, U.S. Environmental Protection Agency). Nine countries participated, seven with direct contributions that provided the basis for the conclusions and recommendations. The study was performed over a 12 month period followed by refinement of the final report and recommendations. Historical information and the list of participants and countries are contained in Appendices A and B.

This summary report was based on the various inputs from the seven active countries. The inputs are contained in detail in a separate Volume II. Of related subject interest is the report "Rational Use of Energy," NATO/CCMS-58, 1977 (which is available through NTIS).

VOLUME I

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1. INTRODUCTION

1.1 Background

Modern society is threatened by shrinking energy resources, limited non-renewable primary materials, and the environmental consequences and inconveniences of its industrial and municipal wastes. A key element in successfully coping with these threats is the development of strategies and technologies which deal with them in an integrated manner. An objective of industrial societies should be to achieve the capability of recovering waste products in an economically feasible and energy-conserving manner that protects the environment. One area of opportunity for recycling is that of plastic wastes.

Achieving the capability of recycling plastic wastes requires adequate and relevant information on the quantity and quality of plastic waste sources, a combination of new and proven technologies, effective systems management, appropriate institutional arrangements, economic incentives and a general acceptability. Consequently, it is appropriate for governments to identify areas where it is currently or potentially feasible to establish integrated approaches and build a foundation for future development.

Plastic is one of the major material types in use today and in the future an increasing number of products will be made from its various forms. Current world production of plastics is approximately 50 million metric tons per year. The increasing use of plastics is due to the many advantages offered, e.g., the combinations of low weight and good strength, chemical resistance, ease of design and processing, as well as low cost. Plastics are only one of the many components found in the solid waste stream. However, they present problems in solid waste management because they are a minor portion of the waste stream relative to weight

and recoverable value, resist degradation, and their environmental impact after disposal is not fully known.

A means to increase heat resistance, fire resistance, life, etc. of plastics is through the use of incorporated chemical additives and modified chemical structures. Some additives and structures are complex and contain chemical elements and compounds that when degraded could introduce irritating or noxious substances into the environment. Environmental hazard concerns may, therefore, contribute to the need for recovery of plastics in the future.

Reduction in the amount of plastic wastes would be highly beneficial with respect to conservation of resources, general economics and the preservation of the environment.

1.2 Scope

The CCMS pilot study was initially envisioned in two phases. Phase I was to be principally an information exchange, encompassing all aspects of the existing publicly available information that is applicable to the recovery, recycling, and disposal of industrial and domestic generated plastic wastes.

The goals for the Phase I information exchange were:

(1) to establish the status of plastics wastes reuse/recycle/recovery in the NATO countries with respect to the industrial and domestic (municipal) sectors

(2) to establish a data base as a result of the compiled data

(3) to identify gaps in the data base

(4) to make recommendations, that if implemented, could promote the recycling of plastic scrap and wastes, and

(5) to identify areas of specific technology or activities of mutual interest that merit further investigation or implementation in Phase II.

Phase II was to be dependent upon and defined by the results of Phase I. Mutually beneficial, co-operative projects in specific areas of plastic wastes recycling potentially could be implemented. However, the information generated in Phase I resulted in the experts group deferring any near-term work (Phase II). It was felt that resolving technological problems would not overcome dominant, economic factors that have countered the widespread recycling of plastic wastes in general.

1.3 Guidelines for the Information Exchange

For the plastic materials that encompass the major portion of the output of the plastics industry, it was considered appropriate to include in an exchange of information a description of:

(1) the wastes from plastic manufacturing, conversion and fabrication processes;

(2) the plastic wastes in municipal refuse;

(3) methods for utilization and/or recovery of plastic wastes;

(4) economic and institutional incentives/barriers:
   (a) for the development or implementation of recycle technologies;
   (b) for the marketing of products made from recycled materials;
   (c) for the marketing of plastic wastes;

(5) environmental, health, resource and occupational impacts from disposal or recycle of plastic wastes;

1.4 Definitions

It is appropriate to provide a set of definitions for discussing the technologies involved in making use of waste plastic materials. The terms that will be used are: reuse, recycling (primary, secondary, and tertiary), waste plastic and scrap

plastic. The terms are defined in this report for clarity of the presentation and not as the basis for a legal precedence.

Reuse (herein distinguished from recycle) is the use of a plastic product a second time in its fabricated form. A good example is a returnable bottle of the type that is cleaned, inspected, filled and made use of in an identical manner as its first use as illustrated in Figure 1.

Recycling implies that the plastic material is changed in physical form and made useful through reprocessing. For thermoplastics, this means that it is remelted. Primary recycling is the reprocessing of the plastic back into its original fabricated shape. Secondary recycling is the reprocessing of the plastic into another useful physical form, i.e., old wire coatings into garden hose. Tertiary recycling is the reprocessing of the plastic into another useful chemical form, i.e., pyrolysis of plastics into waxes or oils or the incineration of plastics for their fuel value.

Scrap plastic is that material that is recyclable in a primary, secondary or tertiary manner through remanufacturing, conversion or fabrication. Manufacture is the generation of plastic through polymerization, conversion is a modification of the plastic by compounding and/or shaping and fabrication is reshaping or joining of the plastic into a useful product.

Waste plastic is that plastic that is in or destined for the disposal area. It includes both manufacturing and post-consumer wastes and can come from original manufacturers, converters, fabricators, users or consumers.

Both scrap and waste plastic were considered in this study with emphasis on the waste plastic. A major emphasis was in defining how to convert useless waste into useful scrap.

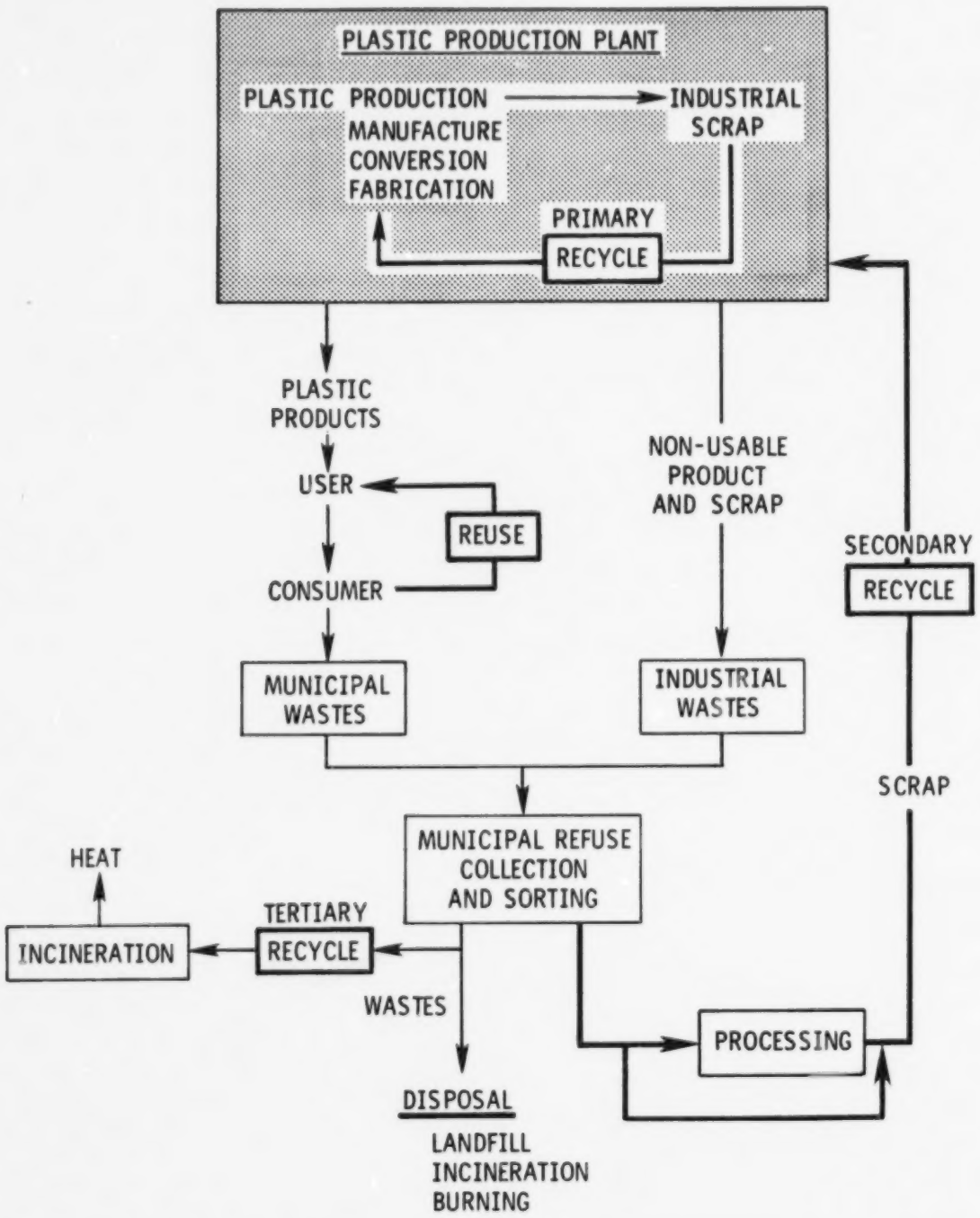


Figure 1. Reuse, recycle and disposal by definition are performed on product, scrap and wastes. The objective of recycling is to minimize wastes by turning them into usable scrap.

2. SUMMARY

The pilot study was conducted with direct participation and contributions by Belgium, France, the Netherlands, Norway, Portugal, the United Kingdom, and United States of America. Spain and Italy also participated. The study consisted primarily of determining the status of plastic scrap and waste recycling in the participating countries, with an analysis of this status to provide general conclusions. Specific recommendations for the participating countries were then generated.

The survey of plastics recycling centered around the perceived major problem area. The major problem area was perceived to lie in municipal mixed refuse containing both industrial and post-consumer wastes. The selection was based on the apparent lack of utilization of large amounts of plastic wastes which are being disposed of in municipal dumps. Recycling of industrial scrap from manufacturing, conversion or fabrication was considered to be a viable functioning reality and documentation was obtained to verify that fact.

The discussion is separated into a review of

(a) the materials and their potential impact on the solid waste streams of the participating countries,

(b) the recycling technologies by country, and

(c) the economics of recycling of plastics based on energy considerations and market influences.

The study was not all inclusive with respect to documentation of specific details, partly due to confidentiality problems. However, the participants were candid about identifying the reasons for past successes and failures.

There was a strong similarity among the participating NATO countries with respect to the nature and relative amounts of their plastic wastes and the viability of recycling technologies. There were, however, some distinct differences which make the results potentially valuable to all participants and provided the basis for a set of recommendations.

Increasing amounts of plastic in the municipal waste stream, increasing material and processing costs and an increasing interest in the conservation of resources and preservation of the environment makes this study most timely and potentially productive.

The information provided by the participants that was the basis of this document and is summarized in the discussion is contained in detail in a separate Volume II.

3. DISCUSSION

3.1 Materials

The consumption (production plus imports less exports) of plastics in the participating countries was found to consist of about 80 percent thermoplastics and 20 percent thermosets (by weight). Five major plastic groups make up 90 percent of the thermoplastics. These plastics are: high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), polystyrene (PS), and polyvinylchloride (PVC). For the purposes of this study all copolymers, etc. of a plastic are incorporated within its primary group.

Only the five highest volume thermoplastics were considered in this effort since they account for over 70 percent of all plastic generated and have a better potential for recyclability. The consumption of the five highest volume (HV) plastics in the seven participating countries is shown in Table 1. This same consumption data is presented in Table 2 as percentages. It is

TABLE 1. CONSUMPTION OF THE HIGH VOLUME PLASTICS BY TYPE FOR THE PARTICIPATING NATO COUNTRIES* (metric tons - 1000)

Country	HDPE	LDPE	PP	PS	PVC	Total
Belgium	48.0	132.0	9.0	43.0	103.0	335.0
France	188.0	560.0	115.0	215.0	650.0	1,728.0
Netherlands	44.0	113.0	18.0	60.0	180.0	415.0
Norway	33.0	57.0	6.5	15.0	55.0	166.5
Portugal	22.0	52.0	23.0	13.0	38.0	148.0
U.K.	123.0	436.0	188.0	214.0	444.0	1,405.0
U.S.A.	2,182.0	3,502.0	1,763.0	2,475.0	2,871.0	12,793.0
Total	2,640.0	4,852.0	2,122.5	3,035.0	4,341.0	16,990.5

TABLE 2. CONSUMPTION OF THE HIGH VOLUME PLASTICS BY TYPE FOR THE PARTICIPATING NATO COUNTRIES* (% of HV plastics)

Country	HDPE	LDPE	PP	PS	PVC	Total
Belgium	14.3	39.4	2.7	12.8	30.7	100.0
France	10.9	32.4	6.7	12.4	37.6	100.0
Netherlands	10.6	27.2	4.3	14.5	43.4	100.0
Norway	19.8	34.2	3.9	9.0	33.9	100.0
Portugal	14.9	35.1	15.5	8.8	25.7	100.0
U.K.	8.8	31.0	13.4	15.2	31.6	100.0
U.S.A.	17.1	27.4	13.8	19.3	22.4	100.0
Total	15.5	28.6	12.5	17.9	25.5	100.0

*Data updated as of: Belgium - 1974-1979; France - 1976; Netherlands - ~1977; Norway - 1979; Portugal - 1977; U.K. - 1976; U.S.A. - 1979.

evident that the ratio of the HV thermoplastics varies from country to country. (Note: the data was not all for the same year, thus there are some inaccuracies in detail, but these do not affect the general conclusions.)

LDPE is the highest volume plastic in all countries except the Netherlands and France (and if considered on a volume rather than weight basis is 15% less there). Other significant findings relative to the distribution of the major plastics within the countries are: there is a low proportion of PVC in the U.S.A. relative to all others; there is a low proportion of PS in Norway and Portugal; there are contrasting proportions of PP between the group of countries of Belgium, France, Netherlands and Norway (low) versus the group of countries of Portugal, U.K. and U.S.A. (moderate); and there is a low proportion of HDPE in the U.K.

The wastes generated from these high volume plastics from all sources (original production, conversion, shipping, etc.) are shown on a weight basis in Table 3 and on a percentage basis in Table 4. Significant is the result of a comparison (slightly distorted because of missing data) between the percentages shown in Table 4 versus Table 2.

The lower percentage of PVC and the higher percentage of LDPE in the waste stream relative to the consumption is noteworthy. This is primarily due to the different useful lives of products made from these materials as a result of the inherent different chemical and functional characteristics of the plastic , i.e., LDPE in short term use packaging versus PVC in long life building materials. This is true even though greater waste generation occurs in the various production stages of PVC due to the required high processing temperatures which degrade the PVC.

TABLE 3. HIGH VOLUME PLASTICS WASTE BY TYPE FOR THE PARTICIPATING NATO COUNTRIES* (metric tons - 1000)

Country	HDPE	LDPE	PP	PS	PVC	Total
Belgium	0.0	0.0	0.0	0.0	0.0	0.0
France	2.2	5.8	2.3	2.1	5.0	17.4
Netherlands	-	106.0+	-	37.6	25.5	169.0
Norway	6.1	30.3	3.1	7.8	7.7	55.0
Portugal	0.0	0.0	0.0	0.0	0.0	0.0
U.K.	0.0	0.0	0.0	0.0	0.0	0.0
U.S.A.	1,193.0	2,849.0	588.0	1,568.0	1,043.0	7,241.0
Total	1,201.3	2,991.1	593.4	1,615.5	1,081.2	7,482.4

Note: Zeros indicate data not available.
+Includes HDPE, LDPE and PP

TABLE 4. HIGH VOLUME PLASTICS WASTE BY TYPE FOR THE PARTICIPATING NATO COUNTRIES* (% of HV plastics)

Country	HDPE	LDPE	PP	PS	PVC	Total
Belgium	0.0	0.0	0.0	0.0	0.0	100.0
France	12.6	33.3	13.2	12.1	28.7	100.0
Netherlands	-	62.7+	-	22.2	15.1	100.0
Norway	0.0	0.0	0.0	0.0	0.0	100.0
U.K.	0.0	0.0	0.0	0.0	0.0	100.0
U.S.A.	16.5	39.3	8.1	21.7	14.4	100.0
Total	16.1	40.0	7.9	21.6	14.4	100.0

Note: Zeros indicate data not available.
+Includes HDPE, LDPE and PP
*Data updated as of: Belgium - 1974-1979; France - 1976; Netherlands - ~1977; Norway - 1979; Portugal - 1977; U.K. - 1976; U.S.A. - 1979.

3.2 Technologies

A variety of technologies, programs and schemes have been conducted, anticipated, or studied during the past decade in attempts to solve, or get ready to solve, expected plastic waste stream and material conservation problems. Various of these activities and results are discussed in this section.

Opinions on success or failure or the reasons for the same may be difficult to support at times due to limitations caused by confidentiality of information. The discussion, however, is candid and is is expected that the conclusions made will be valid independent of specific details, or their lack thereof.

The discussion on recycle technologies is presented on a country by country basis. As much as possible, a discussion of economics is deferred to the next section, however, its affect on results at times will be difficult to separate.

3.2.1 Belgium

Recycling of industrial scrap within the polymerization, conversion, compounding, and application industries makes economic sense and stabilizes availability of plastics in short markets which have occurred in cycles in the last decade. Typical of the ability to recycle scrap is that shown in Table 5.

In essence, whereas 3 to 20 percent of consumption results in unusable product, one fourth to two thirds of that is recycled back into the product as scrap at the converting plant. This recycle is acceptable for two reasons: (a) little degradation of the plastic occurs in the initial processing, and (b) the percentage of scrap mixed into new product is minor relative to the amount of virgin plastic. Saving of the average 8 percent

TABLE 5. SOURCE AND QUANTITIES OF INDUSTRIAL SCRAP AND WASTE GENERATED IN BELGIUM BY CONVERTING TECHNIQUE (1974)

Converting technique	Plastic consumption, tons	Generated scrap, %	Generated waste, %
Injection molding	75,800	5	5
Profile extrusion	83,300	2	1
Film extrusion/blow	133,000	15	5
Blow molding	34,650	1	2
Thermoforming	30,700	15	5
Calendering	20,400	1	2
Total	377,850	8	4

of plastic drives this sector of the recycling industry, making it viable and an ongoing activity.

The various kinds of waste plastics generated in Belgium are shown in Table 6, indicating that urban (consumer) wastes are almost an order of magnitude (10 times) greater than industrial wastes.

TABLE 6. KINDS OF WASTES AND THEIR RELATIVE QUANTITIES IN BELGIUM (1974)

Kind of waste	Waste quantity, tons
Urban	160,000
Industrial	20,670
Agricultural	2,000

Highlighted in Belgium relative to addressing the mixed urban waste plastic problem is the "plastificator," a machine designed to reprocess mixed waste plastics in spite of their thermodynamic incompatability. This was developed by C.R.I.F. (the research center of the Belgium converting industries).

The plastificator (P.P.V.C.) concept hinges around mixing the plastic wastes in the melt to form a real emulsion. The plastic so formed has properties dependent on those of the mixture and its morphology. The advantages claimed for the P.P.V.C. include: the generation of a very fine emulsion resulting in the best available physical properties; a disc plastificator that, through temperature and viscosity self regulation, achieves the emulsion; a minimum residence time (a few seconds) in the melt which allows processing of the most thermally sensitive plastics (PVC); and a regularity of output achieved by the use of a short extrusion screw. A diagram of the P.P.V.C is shown in Figure 2. The utility of the P.P.V.C. is based on the availability of a clean fraction of urban mixed plastic waste.

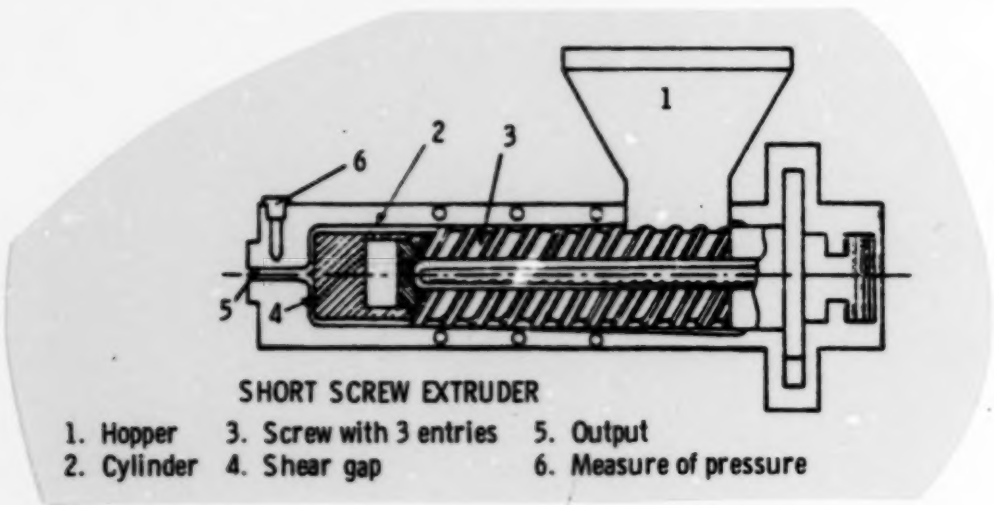


Figure 2. P.P.V.C. plastificator for compounding PVC in PE.

In support of the study to determine the feasibility of utilizing the P.P.V.C., the nature of urban wastes was defined by a study (in the city of Liège); a means for initial grinding, washing, drying and final grinding to a powder were defined; and the nature of a plastic compound incorporating fillers, stabilizers, coloring, etc., was defined (this compound in total goes through

the P.P.V.C. resulting in a homogeneous granular compound usable for injection molding, extrusion and blow-molding covering 90 percent of the industry needs).

The study further included defining potential product applications for the molding compound; defining mold and auxiliary equipment requirements; defining processing conditions while manufacturing products; and performing tests on the manufactured products. Potential applications included: flower pots, small containers, concrete reinforcing rod supports, irrigation pipes, cable covers, concrete forms, bottles, and flat plates.

3.2.2 France

Generally plastic wastes when homogeneous and available in large quantities (greater than one-ton per month), are salvaged by recycling. Manufacturers are recycling more and more of their own scrap as well as that generated by their customers. The amount recycled increases with associated increases in the price of virgin materials.

The volume of waste plastics generated by the conversion industry, relative to the consumption of that industry, is very low. Thus, recycling of scrap represents only a limited potential source of raw materials. Recycling is already generally performed within the conversion and fabrication sectors of the plastics industry, except where limited, such as in the generation of food packaging.

The increasing use of compound plastic laminates (for instance PS-PVC margerine tubs) for cosmetic purposes, reduces the availability of easily recycled materials. Polymer-coated paper packaging also causes some problems, however, PS/Al/Paper residue from dairies is separated and that scrap exported. Printing and labeling also incorporates residues which complicate (but do not prevent) separation and recycling.

Plasticized PVC is readily available to plastic recyclers. A prime source is the heat-sealing fabrication process. An average of 10 to 15% of scrap is generated in the case of PVC use and 10 to 12 percent in the case of PE. This scrap is usually generated by small independent business' who cannot recycle it directly.

Consumption of plastics in France is centered (in relative order of volume) in packaging and manufacturing, construction, consumer goods, automobiles and agriculture. On the average, the lives of plastics for these applications are respectively 0.1-1 year, 10-30 years, 5 years, 8-10 years and 1 year.

Recycling of agricultural waste plastic (primarily LDPE fertilizer bags) was not being done on a large scale, but a significant volume is now expected. Cleaning and separation of foreign matter is required. The technology required to handle the agricultural waste plastics is expected to be very similar to that needed for household refuse. Then any technological developments are expected to be most important for the future. An interesting phenomenon existing in France is the that most fertilizer is delivered in bags, whereas in Germany, bulk deliveries account for over 90% of the product distribution.

As a result of verified increases in crop yields, a rapid increase in the use of plastics in agriculture has occured (90% PE and 10% PVC). The applications include films for mulching, greenhouses, crop shelters and ensilage covers. Means to encourage recovery of agriculture waste plastics are being considered. These include incentives such as deposits, reducing litter in the fields, and preventing the bags from being outlawed.

PVC and PE wastes from wire and cable recovery are presently landfilled or burned. Handling these wastes needs to be further examined. Both separation and mixing are being considered. Mixing involves the Reverzer process which requires that there be

at least 30% polyethylene. This is usually not the case and therefore, additional PE must be added (to act as the binder for the composite material - a PVC filled PE).

A significant source of waste plastics is from supermarkets and large stores, if badly contaminated films can be handled by recyclers. Economically viable recovery of these wastes requires an availability of only 5,000 tons per year. Recovery of the waste requires a collection network for which it is expected that the paper and carton recovers would be responsible. Thus handling an additional 5,000 tons of scrap per year would be possible providing that the generators of the waste participate effectively.

In France about 25% of plastic consumption ends up in household refuse. The preponderance is packaging but that portion has been decreasing slightly over the last five years. The nature of the household refuse varies with the season, affluence of the neighborhood, geograpical location, etc.

Presently, urban refuse is disposed of by landfilling, incineration, and composting. The respective percentages, disposed of in such manner, are 55, 35, and 10 percent.

PVC mineral water bottles (62% of all PVC bottles) are a special and unique case in France. Highlighting this, is that whereas 80,000 tons are used in France, only 35,000 and 23,000 tons are used in the USA and Germany, respectively. An increase in the quantity of PVC to be recovered and recycled is planned by the Ministry of Industry in collaboration with various companies. This group, working together, is targeting a savings of a fuel equivalent of 60,000 tons by 1985. In support of their efforts, they have defined a national price for recycled PVC (at 900 francs per ton), derived a formulated return for recyclers, and are providing technical assistance in the areas of collection,

handling and transportation. They also guarantee to place new products on the market which are made from the recycled PVC. Their efforts will hinge around a localized collection of the PVC mineral water bottles and for this, they have suggested various types of collection including supplementary and selective collections.

Two waste separation processes are well-developed in France. They are the COMBUSOC-TRISOC processes of the SOCEA company and the REVALORD process developed by BRGM, Carel Fouche Company, LuChaire Company, Mokta Company and TRIGA. The TRISOC process was targeted toward making a plastic concentrate. However, more recently the COMBUSOC process is being directed toward the manufacture of a combustible solid (refuse derived fuel). The REVALORD process involves mechanical separation of the entire municipal stream. A 100,000 ton per year unit is soon to be in service at Nancy and will furnish 1,000 tons per year of PVC to recyclers. The success of this full-scale plant is important to the recycling industry in France and in general. It could provide the means and material which together with the other defined infrastructures could set the pace for the practicality of recycling of municipal refuse.

A syndicate of recyclers was created in 1976 with eight members. Its objectives were to: establish statistics about the business, implement better communications and management, and improve the business image of recyclers and recycled materials (partly by creation of standards of recycled plastics). This organization is still functioning effectively.

3.2.3 The Netherlands

The composition of household refuse in The Netherlands is shown in Figure 3 which indicates that plastic represents 5 percent of the total. This distribution data was generated in an extensive

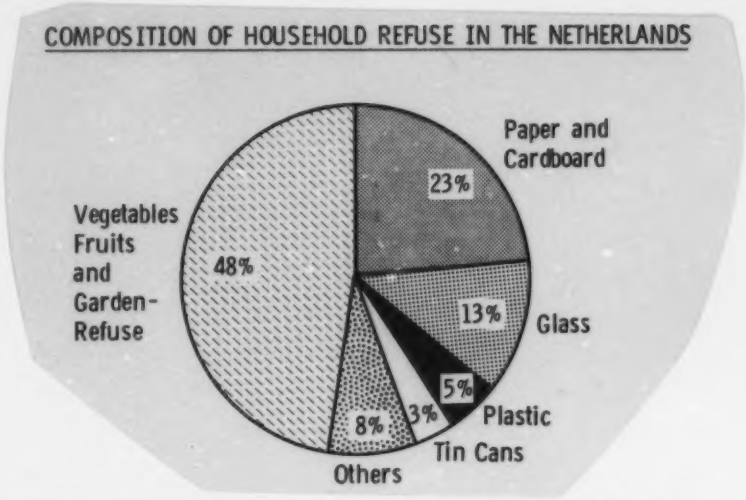


Figure 3. The composition of household refuse in The Netherlands has been accurately quantified.

set of sorting tests by The Netherlands government institute S.V.A. and is considered to be relatively representative.

Three separate and independant research initiatives on the recycling of solid household refuse, with special emphasis on the re-use of the separated components were proposed in The Netherlands. The three initiatives were subsequently combined and TNO, Esmil B.V. and Recycling B.V. jointly formed a research program with a basic goal to separate municipal refuse into the largest number of re-usable components. It was the team's opinion, however, that future economies could not possibly absorb the cost if traditional municipal refuse handling systems were used.

The answer toward achieving the goal was hypothesized to be the development of a refuse separating plant, which should be more favorable economically than those using existing methods of refuse disposal.

A number of years of extensive research, funded by both industry and government, resulted in a 15 - 20 tons per hour refuse separation system. It was integrated into an existing municipal waste plant and operated. An outline of the plant process and relative output are shown in Figure 4. Ever since the basic research program was completed, the system has produced re-usable materials at the ~20 ton/hr capacity.

The extent of separation achieved with this system is such that recyclable materials could be used as raw materials for the various material industries without any extra cleaning and/or other treatment.

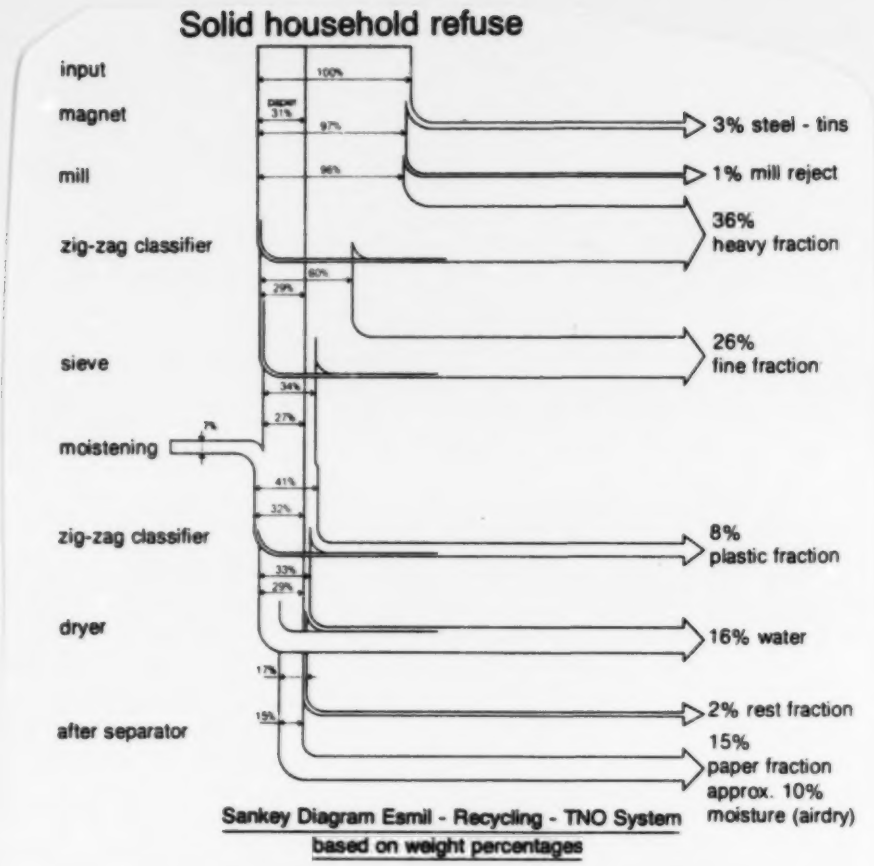
The government controlled national laboratories (TNO) have issued a number of technical reports, supporting the practical applications of the recovered materials. At the same time and with the collaboration of the various industries, large scale tests were carried out to substantiate the practical suitability of the recycled components.

The system has the following claimed features:

- relatively low investment costs
- simple operation
- low operational cost per ton of refuse for say a 40 ton/hour system
- no environmental side-effects.

As a result of the large scale pilot separations tests, it was concluded that:

- a variable capacity is possible relative to the quantity and quality of end-product
- a combination of one or more end-products is available



Based on the average composition of the refuse, the plant gives the following results:

	degree of separation on airdry basis	degree of cleanliness
paper	70 - 80%	approx. 5% plastic and straw 0.9% sand
plastic folio	70 - 80%	1% mainly paper
steel-tins	95%	5%
fine fraction	–	–

Figure 4. Outline of the municipal refuse separating-plant process developed in The Netherlands.

- the system can be adjusted to accomodate the variable composition of refuse
- end-products can be used as raw materials by the converting and fabrication industries
- system reliability exists because of its inherent mechanical simplicity.

Actual recycling of the plastic components separated by the plant is being further examined but is not now a practical reality. Reprocessing of the wastes into relatively low modulus second grade materials, mainly PE film and also other potential products, is being examined.

Separate from the above described work, processing of industrial olefinic (PE and PP) wastes, sometimes in combination with paper (cellulosic fibers), into molding granules is performed. These are converted (extruded) into such products as 10 cm diameter fence posts by a process of the Lankhorst Company.

A separation plant is under construction at Vam-Flaekt. 125,000 tons per year of municipal refuse are to be separated into fractions on a commercial basis. A plastic fraction of about 5,000 tons per year is expected.

The use of PVC wastes for de-tinning metals, that are also in the waste stream, is being examined. This represents a potential use of one waste in an other than natural form to assist in recycling another potential waste. Consideration of other potentially synergistic uses of the total waste streams presents an interesting approach to the overall problem.

Earlier attempts at recycling of plastic wastes were considered to have failed for a variety of reasons which included: the comparatively low prices of virgin plastics, the degradation of

physical properties, loss of favorable appearance of resultant products, greater manufacturing losses, and greater wear on plastic processing equipment.

3.2.4 Norway

Eighty-four percent of the total plastic waste in Norway is in the form of domestic (consumer) wastes and this proportion is expected to increase in coming years. There is a trend toward a disappearance of homogeneous industrial plastic wastes. Producers of PVC and PE have to a certain extent already found a market for their waste (thus converting waste into scrap).

Increased conversion of potential wastes into scrap also is increasing for plastic fabricators. Presently a group of the largest plasticized PVC fabricators are considering buying a common plant to produce processable granulate from their PVC wastes. This will reduce industrial wastes. LDPE film wastes are also expected to be reduced. An existing company, that now exports 700 tons of such waste converted to scrap, is expected to export significantly more in upcoming years. This same company is considering the possibility of buying equipment for granulating all types of industrial thermoplastic waste to allow recycling it back into the economy.

A process for the mechanical separation of plastics wastes had been developed by SINTEF (SINTEF Report No. STF21 A78081). A flow chart of this process is shown in Figure 5. The process includes multiple shredding and screening stages followed by air classification, grinding, washing, dewatering, and drying.

A further study has been conducted on the purification and granulation of mechanically separated plastics (SINTEF Report No. STF21 A79043.)

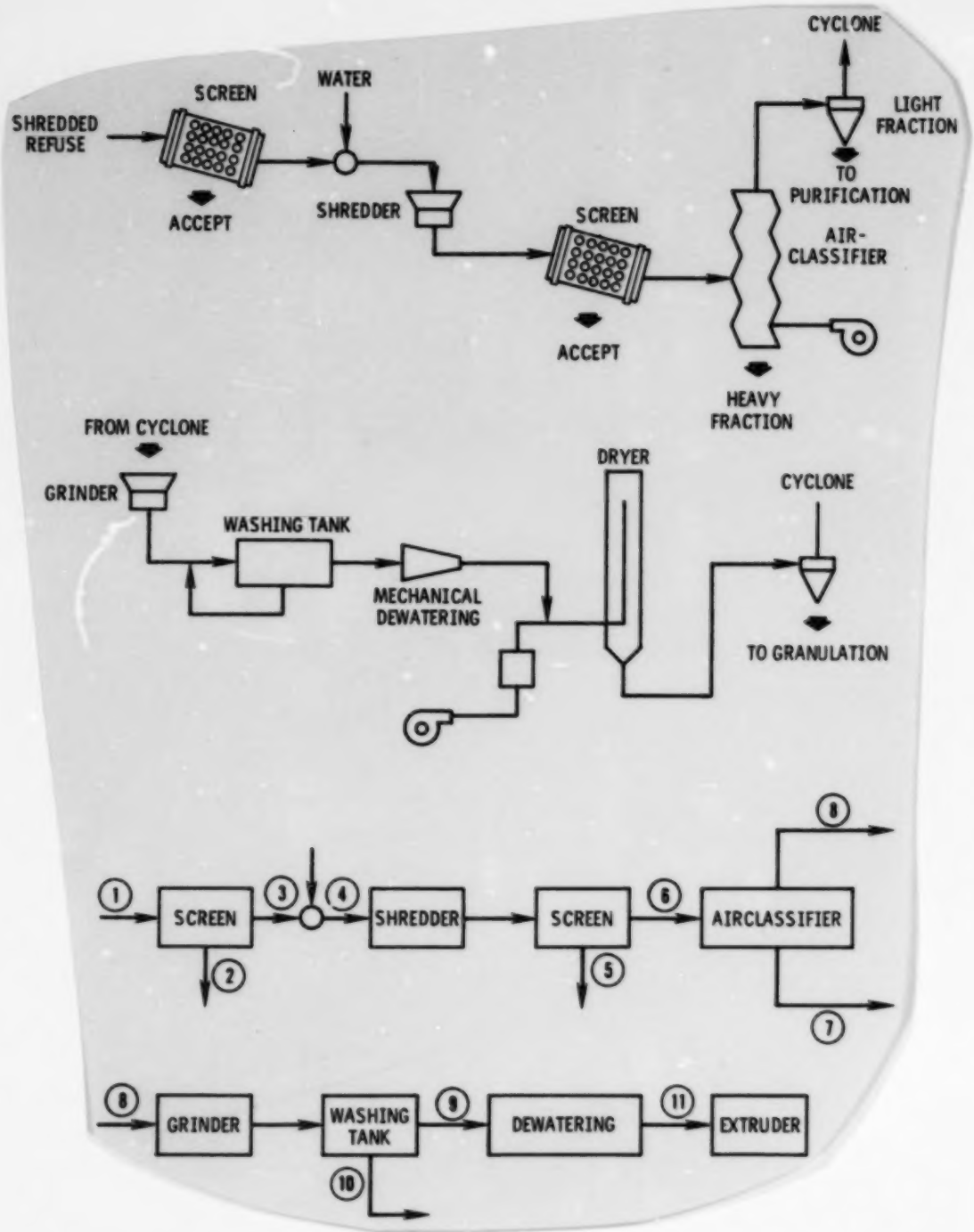


Figure 5. Flow chart for mechanical separation of plastic wastes by process developed by SINTEF in Norway.

Foamed polystyrene plastic prills (BASF Germany) have been used as fillers for concrete for 10-15 years (PS concrete). This product, however, has not achieved the expected level of use due to difficulties in obtaining building code approvals and in performing standardization work. Increasing oil prices also cause the product to become more costly compared with conventional materials. The Central Institute for Industrial Research in Norway has performed a project where waste plastics have been foamed and used as fillers in cement and polyester. The material used is ordinary industrial sorted plastic or mixed wastes of random quality, to which has been added a foaming agent on extrusion.

From these recycled products have been made sandwich structures with reinforced polyester skins and blocks consisting of the foamed prills bonded with polyester and cement. The strengths of these structures were investigated and the values have proved to be so acceptable that it would seem that the structures can be used as load bearing and semi-load bearing structures. Concrete structures with fillers of the foamed waste plastic cost more than conventional structures. However, the properties of this concrete in production, casting and use afford advantages for which the user may be willing to pay. Among these advantages are: diffusion resistance, relative density lower than 1 and the ability to shape the product, for example by sawing.

3.2.5 Portugal

The nature, treatment, reuse, recycling, etc. of wastes are less well defined in Portugal in general. Known is that the collection of urban wastes is limited for a variety of reasons. One reason is that over 70 percent of the population lives in a rural situation. Secondly, there is only a limited availability of adequate water supplies, sewage and waste systems, and these correctly have a higher priority.

For the most part, urban wastes are disposed of in open dumps without any sanitary conditions. It is expected that a certain degree of recycling occurs through a scouring of these dumps by ragpickers, etc. "Ragpicking" is itself a well developed "recycling industry" which prospers in the less developed countries.

The basic sanitation law, approved in October, 1976, laid the way for every settlement with a population of over 500 to be equipped with adequate water, sewage, and waste systems by 1990.

The portion of plastic wastes in municipal refuse (estimated roughly from those in Lisbon) is about 3-4 percent with organic wastes ranging from 65 to 70 percent. This percentage increases between the sources and the dumps due to the action of ragpickers removing the more valued products. Otherwise, recycling or reuse of plastics is practically nonexistent.

There is expected that a petrochemical industry will start in Portugal in 1980 (Olefins) with aromatics following in 1981. This fact has introduced an emphasis to improve the general quality of life which should introduce recycling and the conservation of resources. The effect of this conservation on the balance of payments and the economic well-being of Portugal is also considered a strong driving force.

There is presently an active plastic conversion and fabrication industry which takes advantage of the recycling of its industrial scrap. Plastics included are LDPE, HDPE, and PP, primarily in the form of films or fibers (ropes, nets, etc.).

There are three units for the re-utilization of raw materials with a capacity of 150 tons per month. Wastes of similar properties are directly or indirectly collected by interested parties.

3.2.6 United Kingdom

The total U.K. consumption of plastics is around 2 million tonnes/year, of which 70% consists of thermoplastics, mainly polyethylene, polypropylene, polystyrene and PVC. A large proportion of this material is used in the manufacture of products with a very short life. It is estimated that approximately 800,000 tonnes/year of plastics are contained in household waste, and about 150,000 tonnes/year in industrial and commercial waste, so it appears that about half of U.K. plastics consumption is discarded after a very short lifetime and disposed of by tipping.

This substantial loss of resources has been recognised by Government, Industry and the Universities, and all three sectors have been involved in attemps to promote recycling of waste thermoplastics. The Department of Industry's Warren Spring Laboratory reviewed the situation in 1977, and a report generated entitled "Waste Plastics and their Potential for Recycle" (Appendix E). Since that time the British Plastics Federation has made further enquires within the polymer conversion industry, and some statistics from this source were generated (Appendix E).

In the academic world two Universities are recognised as having particular expertise in the recycling of polymers - Brunel and Aston. Both of these Universities are receiving funds from the Department of Industry for their research. Investigations in progress include methods for the separation and cleaning of mixed and contaminated polymer products, the development of chemical additives to counteract the degradation of secondary polymers during moulding, and the processing of mixtures of different polymers.

In the industrial sector recovery of clean, segregated polymer scrap is already very efficiently carried out, and it is doubtful whether there is any room for significant improvement. Several

companies have developed processes to use the 150,000 tonnes/year of mixed and contaminated polymer waste from industrial and commercial sources. These processes range from the recovery of clean reusable polymer from specific sources of waste, such as fertilizer sacks or cable scrap where the plastic is contaminated but of know composition, to the conversion of mixed polymer waste into board or sheet products or simple moulded objects of thick cross section for non-critical applications. The comments made about these processes (ref Appendix E) are now out of date, and it is therefore appropriate to discuss the current situation. Unfortunately several projects have failed since 1977, but attempts are being made to find out what problems were encountered, and what lessons can be learned for the future.

In 1971 Regal Packaging Ltd set up the first waste plastic board-making process in the U.K. The basic process consisted of granulating a mixture of plastics, depositing the granules on to a moving belt, and passing them through a gas heated oven where the granules were caused to fuse. The fused granules were then moulded to shape in a press. The Regal process had a number of important advantages, including tolerance to foreign matter (e.g. stones) in the mixture, ability to cope with a wide range of mixtures of waste plastics (including therosets) and operational simplicity. Further development was needed, however and in 1975 a continuous process was designed in association with Spooner Dryers Ltd.

A plant using the full scale Spooners unit is now operated in Worcester by Plastic Recycling Ltd. The product, stokboard, consists of 8 ft x 4 ft sheets with facings of polyethylene, usually in black, to present a uniform appearance. It is marketed predominantly in the agricultural industry for use in piggeries, cowsheds, chicken houses etc.

In 1976 a board-making plant using mixed waste plastics as the raw material was opened by Reclamat, Ltd. The process, similar

to Regal in the granulating and fusion stages, differed in two respects. It used a core of mixed waste plastics (50% thermoplastic) and an outer skin of black PE or PP. Thus, there were extra process stages, i.e., production of a pelleted black masterbatch and a three stage deposition of the granules on to the belt. The process was continuous resulting in a 4 ft wide 3/8 - 1/2 in. thick sheet.

The Reclamat process ran into financial difficulity quite quickly and the financial support was lost. Attempts at reviving the venture have so far been unsuccessful.

The well known Reverzer process (Mitsubishi Petrochemical Co., Japan) was operated by Laporte Industries Ltd, starting in 1976. Laporte energetically promoted new markets for products such as posts for electrified fencing and slatted floors for pig pens, in which the mixed plastics product had advantages over competing materials. Demand was high, but the company experienced technical difficulities and the plant was closed in 1979.

Other companies have developed processes to recycle specific types of plastics waste. A subsidiary of the Dickinson Robinson Group, DRG Kent Plastic Sacks, developed a process in which used fertilizer sacks were granulated, washed and dried. The clean flake was then extruded, pelletised, compounded with other resins and colouring agents for conversion into refuse sacks. It was recently announced, however, that this plant was being closed down. Another specialised development is a washing and separation process devised by Professor Bevis of Brunel University, which has been taken over by a Company and used in a pilot plant for separating polythylene and PVC from cable scrap. Recently Avrotone Ltd of Kettering has announced a process for separating mixtures of polymers from a variety of waste materials. Details of this process are still confidential.

In summary, attempts to recycle mixed and contaminated waste plastics in the U.K. have not met with a great degree of success. Nevertheless, in spite of the obvious difficulities and many failures in the past, interest in recycling plastics continues to be strong and new attempts to do so on a commercial basis continue to be started.

3.2.7 United States of America

Recycling of scrap is performed in the United States with various degrees of success. This recycling can be categorized into two types. First for the case where relatively pure (neat) materials are recovered usually from mixed plastics and secondly for the case where mixtures of plastic wastes are upgraded to scrap and used "as is" to fabricate a useful product.

Both thermoplastics and thermosets are recovered. However, generally the more successful operations consist of the recycling of industrial scrap which is available in large quantities.

3.2.7.1 Recovery of Relatively Pure Neat Plastic

The major efforts in this category consist of (a) recovery of PVC from coated fabric scrap, (b) recovery of PVC and PE from wire and cable insulation, (c) recycling of waste PET plastic soft drink bottles, (d) recycling of PP battery cases into molding compound, (e) recovery of urethane cushioning wastes, and (f) recovery of specific PVC, ABS and PS scrap and wastes.

(a) Plastic Coated Fabrics - Over 30,000 tons of fabric waste are generated in upholstery manufacturing supportive of the automotive and furniture industries. The quantity of this waste has made it an attractive target for recovery. The waste is relatively clean and well defined. (It should be noted that included

in this waste are cotten fibers also of considerable value.) In spite of these facts no viable business is presently functioning which provides for recovery of the PVC from these wastes.

The Polymer Recovery Corporation was one of the first enterprises to attempt to develop commercial products based on this waste stream. A schematic of their process is shown in Figure 6. This company was about to construct a plant based on a pilot operation, but construction was terminated due to a technical imperfection. They were unable to produce a colorless plasticized PVC demanded of the marketplace.

Gerwain Corporation and Hafner Industries have also attempted to attack this potential market with similar solvent separation processes. They apparently have resolved the technical problem of producing a marketable product (which includes the recovered fibers and plasticizers). The economics, however, are still questionable especially relative to competetive virgin materials. Attempts at acquiring venture capital are continuing.

(b) Electrical Insulation - Wire and cable insulation wastes are among the more significant plastic wastes (both manufacturing and consumer) worldwide. They have the added advantage of being tied to valuable metals which themselves are worth recovering. This intimacy with the metal is a complicating factor in the recovery of the plastic which in its absence could substantially change the picture favorably. It is this intimacy, however, that makes the plastic valuable for the application.

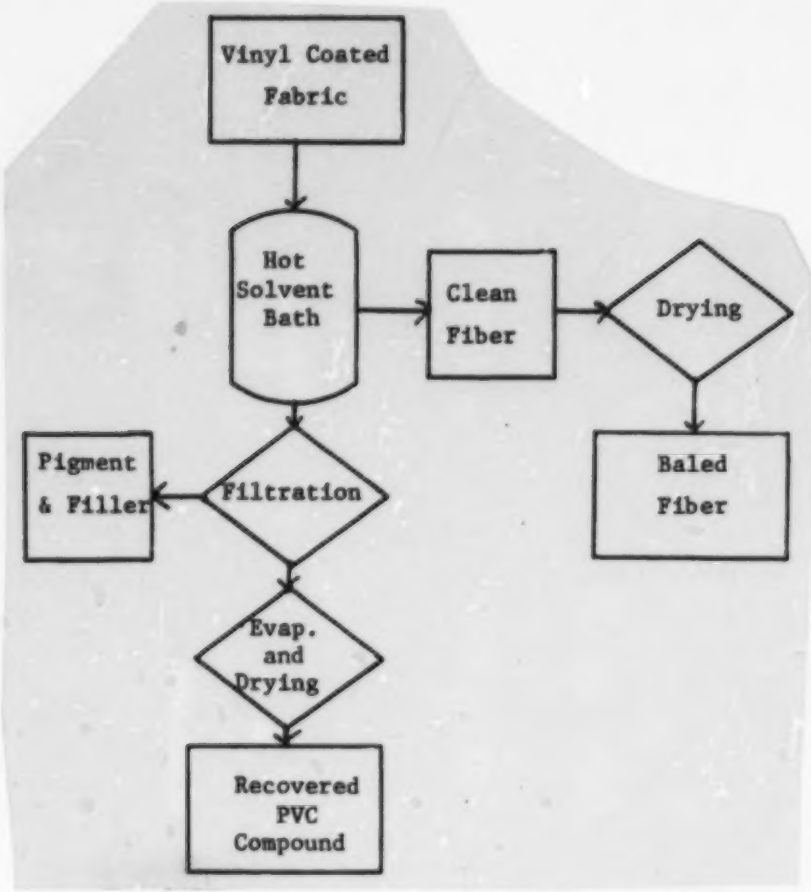


Figure 6. Polymer Recovery Corp. process.

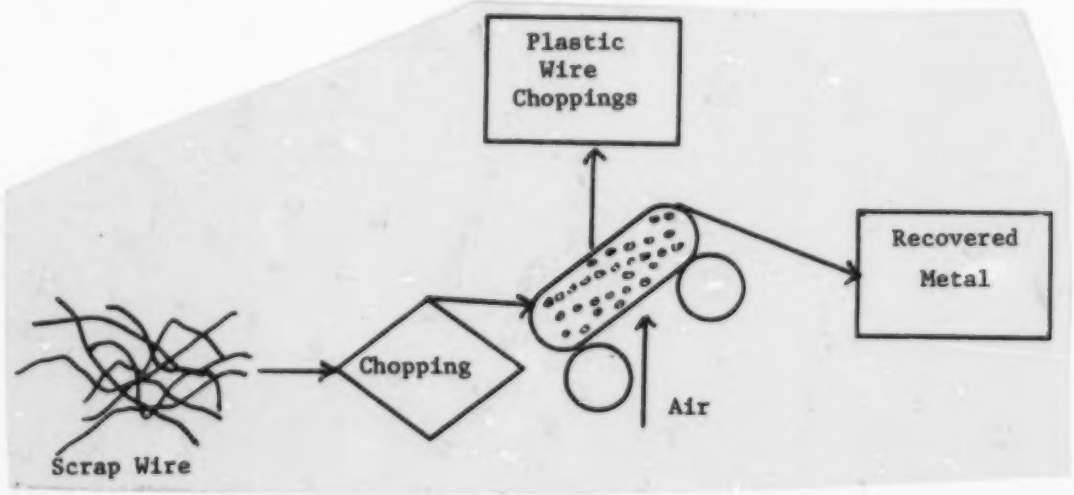


Figure 7. Recovery of metal and plastics from insulated wire scrap.

Recovery of the metal from this scrap is a practiced technology. Typically, wire choppers are used to separate the metal from the plastic as illustrated schematically in Figure 7.

More recently a number of U.S. companies have developed float separation/solvent extraction processes for separating the mixture into relatively pure fractions of PVC and PE. The process, typified in Figure 8, is practiced by Chem-Ecol and Ore Corporation and other smaller wire and cable manufacturers. Western Electric which generates large volumes of these wastes has a pilot process, that has not been commercialized mainly for business reasons.

Removing the last traces of metal from the plastic before reuse as an electrical insulation is normally difficult, but necessary for the application. Western Electric has found that electrostatics can be used to remove even trace amounts of copper. The PVC so recovered can be used in jacketing, sheathing or insulation for low voltage automotive wiring or a variety of non-electrical injection molded goods.

Chem-Ecol (Cleveland, Ohio) reprocesses segregated PVC insulation wastes on a toll basis. The reclaimed product is used primarily for low voltage automotive wiring insulation.

Ore Corporation (Fort Wayne, Indiana) has a new plant with a capacity of 7.5 million pounds per year for the recovery of PE from wire scrap. The recovered PE is compounded with carbon black resulting in a product very similar to the virgin material. However, the wire and cable industry prefers to use only virgin material

in their insulation, thus this non-captive source must sell to molders and extruders who fabricate automotive parts, irrigation pipe and flower pots.

At least two separate wire and cable manufacturers chop their wire wastes to recover the copper. In so doing they segregate the plastic which simplifies the recovery of relatively pure PVC then used in jacketing.

To provide some perspective into the economics of recycling PVC from wire and cable insulation, the economics relative to operating a plant like that illustrated in Figure 8, were estimated based on 1977 costs and prices. A processing cost (exclusive of compounding) was estimated to be 8-9 cents per pound at a time when PVC virgin molding pellets were being sold (delivered) for 28-35 cents per pound. Accordingly a viable business venture could exist if the scrap and transportation costs were in line (indicating the need for proper geographical location). The fact that the recovery of plastics from wire and cable is viable is proven by its existence, thus the economics must be correct.

(c) Soft Drink Bottles - A major evolution in beverage containers is occurring in the United States with the advent of the polyethylene terephthalate (PET) 2 liter container. In 1979 1.2-1.5 billion containers were used. These containers are not reusable (not sterilizable) and thus represent a potential major litter problem in addition to the usual consumer waste situation. The petrochemical resources they represent also makes them an attractive target for recovery. The plastics industry is keenly interested in developing schemes for recycling the empty containers partly because of concerns for them being ligislated out of

existence if they become an apparent or real litter problem.

A major problem in the recycling of these PET containers is the problem of collecting the relatively large bulky containers. The collection problem is being resolved in at least five states in the U.S. by legislated beverage container deposits, inclusive of plastic, glass and metals (5-10 cents per container). Voluntary collection is also being pursued in a few other states.

In the state of Michigan, which has been operating for more than one year under a deposit system, it is estimated that about 75 percent of the containers are being returned by the consumer. The remaining containers end up in the municipal waste stream. Overall it is estimated that about 5 percent of all PET containers used in the U.S.A. are being recovered for potential recycling. Reuse in food packaging is unlikely.

The handling practice in Michigan is to grind the bottles at the bottler's facility to reduce volume for either transport or disposal. Their resilience makes them difficult to flatten. DuPont (Material Reclamation System) and Wellman, Inc. have been purchasing the bottles for from 2-8 cents per pound depending on the quality of the scrap and the distance between the bottler and the reprocessing plant.

On the surface the economics do not appear very favorable for the bottler because grinding costs are at least 5 cents per pound. However, in the states requiring deposits the bottler's only option is to transport to a landfill. Landfilling is expensive because of the bulkiness of the container and if the container is

retrieved from the dumpsite the bottler is required to pay a double deposit.

An added complicating factor to the PET bottle container is that it is only (with one exception) 75 percent PET. Twenty-two percent is a PE base and the remainder is an aluminum closure (1.4 percent), a paper label and adhesive. The closure contains an ethylene vinyl acetate liner.

Recovery of PET from this mixture requires a sophisticated technology. Both DuPont and Goodyear Tire and Rubber Company, manufacturers of the PET resin, have developed usable technology. DuPont has set up a facility in North Carolina for recovering relatively pure PET and possibly PE by a proprietary process. The recovered PET contains small amounts of paper fiber that has detracted from its value.

Goodyear Tire and Rubber has also developed a separation system. A 100 lb/hr pilot plant uses water and air separation media. The paper is removed during air separation because the paper is lighter than the plastic. The PET and PE are separated by flotation of the PE in water. Aluminum is removed in a liquid cyclone separator.

The separated PET scrap is useful for a variety of non-food applications such as fiberfill, corrugated sheeting, floor tile, strapping and cordage. DuPont has an active program to determine the best internal end-use application for the recovered PET. Eastman Chemical is also interested and recently reported on their attempts to recover PET for use as a raw material in the manufacture of unsaturated polyester. They have concluded that this use will save raw material costs, reduce processing

costs due to faster reaction times, and result in higher yields.

The PET plastic container has considerable functional advantages over other types. There is thus a desire for its existence. A large plastic market is also apparent that can penetrate into the large glass industry's share. The driving forces to make PET work are great and thus resources to resolve the disposal problem will be made available by vested interests.

(d) PP Battery Cases - A number of companies in the U.S.A. currently recycle polypropylene from discarded automobile batteries. The scrap is reprocessed and foam extruded into bed frames and other products such as strapping. The polypropylene scrap is usually contaminated with rubber from older batteries. The rubber is removed in a flotation process.

(e) Foamed Polyurethane Recycling - Polyurethane foam (a thermoset) is used extensively in automotive and furniture cushioning in large volumes generating intractable scrap. The industry has been looking for ways to use this waste. One company recycles the waste into carpet underlay by first shredding it and then adhesive bonding the shreds together. General Motors and Ford have developed processes for hydrolyzing the scrap back into diamines and glycols. A schematic of this process is shown in Figure 9. At this time the economics of the process are relatively poor.

In the General Motors process the foam waste is fed into a reaction chamber and contacted with dry super-heated steam at atmospheric pressure and 232-316°C. The dry polyol is removed from the reaction zone and can be

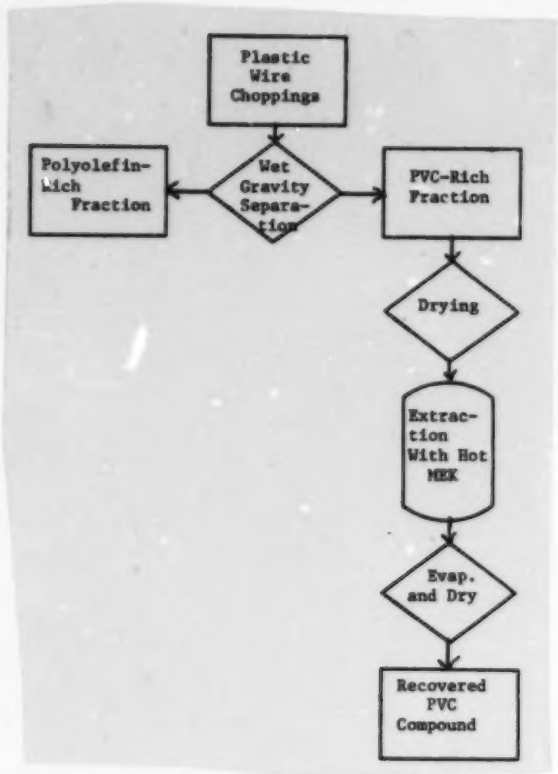


Figure 8. Recovery of PVC compound from wire choppings.

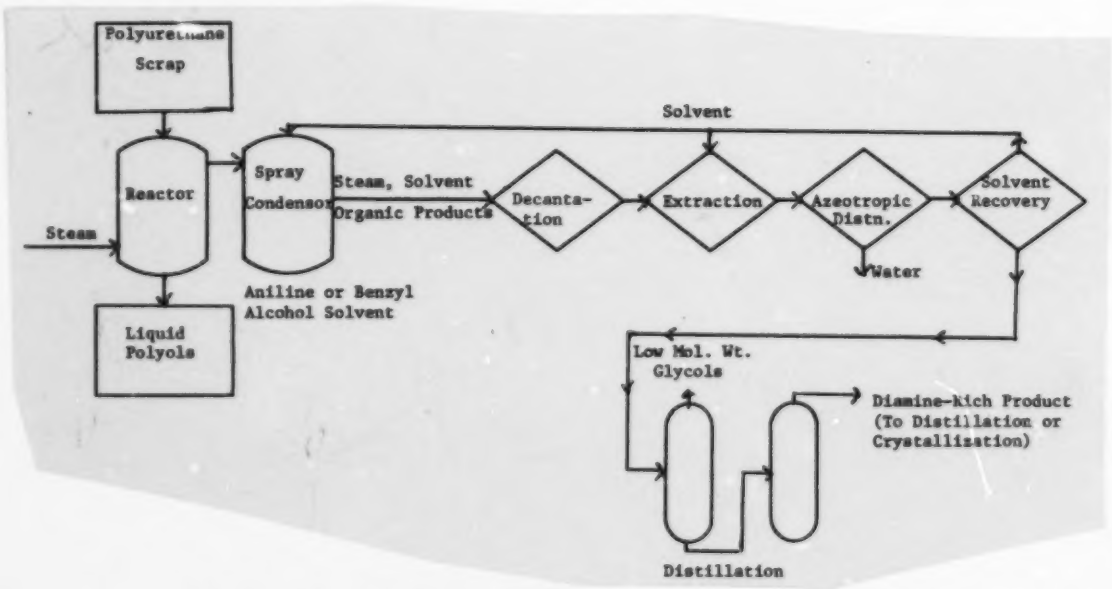


Figure 9. General Motors' recovery process for flexible polyurethanes.

reused as is. The isocyanate is converted to a diamine which is extracted from the condensate. Foams have been made with up to 20 percent of the reclaimed polyol.

(f) Miscellaneous Scrap - Other successful recycling scrap ventures exist that can conserve additional PVC, ABS and PS.

Gerwain Corporation, mentioned above, recompounds a variety of plasticized, semi-rigid and rigid PVC wastes from manufacturers by a proprietary process to yield a compound which is used in building wire insulation. The significance of this recycling process is the relatively high quality application. Generally PVC is recycled into such products as garden hose having minimal properties.

Western Electric has been recycling 7 of 10 million pounds of its ABS wastes annually over the past few years. The recovered ABS is of sufficient quality to be reused in many of Western Electric's molded products.

Free-Flow Packaging Corporation has a very successful commercial process for converting industrial PS scrap into spaghetti-like dunnage. This product is manufactured from 100 percent recycled material. The company now has a plant in Europe.

3.2.7.2 Products Based on Mixed Plastics

If mixtures of different plastics are not separated but processed as a mix, the resulting products have poor physical properties--they are often cheesy and brittle because most polymers are incompatible. They do not adhere to each other. Generally, the greater the number of plastic components in a blend, the poorer

are its properties. Nevertheless, there are ways of improving the mechanical properties of products made from mixed plastics. For example, one can simply fabricate thick parts and thus minimize the poor properties of the mixture. Or the mixture can be used as a core material in a sandwich construction where virgin plastics form the outside and waste plastics, the inside. Still, another approach is to combine the mixed plastic wastes with non-plastic components such as air, gravel, sand, glass, wood, paper, textiles, metal filings, or concrete. This approach can improve the mechanical properties of the resulting product because non-plastic components will often stop the propagation of cracks when the plastic product is impacted. Finally, one can use compatibilizers such as chlorinated polyethylene to improve the properties of the blend. However, this is an expensive approach because one normally requires as much as 20 percent of the more costly compatibilizers to achieve good mechanical properties.

(a) Mixed Fabric, Vinyl, and Urethane Foam Wastes - In the United States, General Motors, Ford, and Chrysler use a mixture of waste plastic materials for their trunk mats. The fabrication is normally done by an outside vendor. Mats are made by shredding fabric vinyl, and urethane foam scraps and impregnating this scrap with PVC resin as the binder.

(b) Incorporation of Non-Plastic Materials - Recycling based on mixtures of plastic wastes combined with non-plastic materials has been studied by companies in the U.S. and elsewhere. However, few of these processes have become commercial either because of poor economics or a technical flaw. One of the simplest materials and techniques for incorporating a non-plastic material into plastic waste is foaming. Here, the entrapped air tends to improve the impact resistance of the product.

Phillips Petroleum, in the United States, has demonstrated that they can make a useful product such as a planter by simply foaming a mixture of 50 percent polyethylene, 25 percent PVC, and 25 percent polystyrene. However, this foamed product is not commercial.

Another significant non-plastic material that is frequently used with waste plastics is wood. In the United States, Koenig and Sons developed a process that combines mixed polyolefin wastes, primarily low-density polyethylene, together with wood flour to fabricate pallets. This process was semi-commercial for a time, but the operation was halted because of a technical difficulty--the pallets lacked sufficient rigidity for this end-use application.

Others in the United States and elsewhere have combined waste plastics with glass. In the United States, a company developed a low-pressure molding process that combines one part of plastic waste with as much as one part of glass waste. The molded products included synthetic slate, patio blocks, and flooring. This company was commercial at one time but is now defunct due to poor management rather than the ability to solve both technical and economic problems of plastics recycling.

3.3 Economics

3.3.1 Energy Considerations

The equivalence of plastics with energy is inherent in their origin and the requirements to convert them to useful products. The relationship often introduces the question "Why not just burn the plastic wastes for their fuel value?"

In the absence of economic or conservation driving forces burning or incinerating may indeed represent a viable practical alternative. The greater general acceptance of the world's limited organic resources, however has introduced conservation into regulatory actions that are "encouraging" its consideration.

The energy required to produce the major thermoplastics ranges from 6 to 16 kwh/kg as shown in Table 7. Using the composition of plastic waste in Belgium, the mean energy consumption for plastics contained in municipal refuse is Ca. 14 kwh/kg. Of the total energy required to produce the plastics only 4-5 percent is needed for the converting process, thus when plastics are recycled savings of up to 95 percent of the energy can result. Accordingly, an economic driving force can be available in an appropriate climate.

TABLE 7. THE ENERGY NECESSARY TO PRODUCE THE MAJOR THERMOPLASTICS

Material	Required energy, kwh/kg
Polystyrene	6.0
HDPE	7.6
LDPE	14.75
PVC	16.20

3.3.2 The Price of Plastic Material Wastes

Plastic scrap is in reality a by-product of industrial businesses which handle either thermoplastic raw materials (injection molding, extrusion, blow molding), semi-finished products (thermoforming), or finished products (assembly plants, distribution, consumers).

It is a by-product (scrap) as long as it has a value in a market within given constraints. As a result of this value, the current

market price for virgin material, the costs of collection and transportation, and the cost for ultimate disposal, that waste which was to be discarded or incinerated can become a by-product (scrap).

In other words, if the prices climb in the market for plastics, the industrial plants will save what they normally discard, thereby increasing the volume of scrap available and thus forcing a regulation of the prices; i.e., waste will be converted into scrap depending on the current prices.

It will be noted that when market prices are very low, it is difficult to cover the price of collection and transportation. Waste plastics thus have, in fact, a minimum price which in France can be set at about 0.60 Fr/kg. Above this price, encountered in periods of weak activity (beginning of 1975, 1978), the price of the waste product follows the price of the virgin resin, as a result of the regulation mechanism.

Given this situation, the margin available for recycling the waste products (sale price of the recycled material - purchase price of the waste product) is going to decrease when the prices of virgin resins drop, rendering the economic viability of recycling operations very uncertain. In contrast, when the prices are increasing, it becomes possible to develop more sophisticated recycling procedures.

These remarks are valid only for the high volume polymers (low density PE, high density PE, PP, PS). PVC is in an obviously different position. The technical requirements to recycle are greater, thus large quantities of it do not find a market and remain available at rather low prices.

The more sophisticated polymers (ABS, Nylon, etc.) do not obey any general rule since each lot of waste has unique properties. The available volume is also a great deal smaller.

3.3.3 Price of Prime Recycled Materials

Recycled plastics are used by the converters to produce products which can have characteristics slightly inferior to those from virgin plastics. Consequently, the prices of the recycled products are not in the same range as the virgin resins but are equivalent to those of substandard granules which are sold by the producers at discounts dependent on the state of the market.

Under normal conditions, when sales are good, substandard granules are put on the market in limited quantities at prices which are 10 to 15 percent less than those of virgin resins. Under these conditions, recycled granules are easily sold at prices 20% lower than those of virgin products.

When the market is depressed, an abnormally high quantity of virgin resins are rejected by the producers and sold at discounts that are sometimes significant. This phenomenon causes a rather large drop of the sales price of recycled materials and thus the margin available for covering the cost of recycling. Such, for example, is the case for low density polyethylene.

The same phenomenon is encountered for other high volume thermoplastics. In contrast, for the more sophisticated resins (Nylon, etc.), the discounts are relatively large, but the margins are maintained due to the high cost of the virgin resins.

4. CONCLUSIONS

The conclusions are grouped by categories consisting of a) plastics availability, b) motives for recycling, c) technologies of recycling, and d) products/markets for recycled plastics.

4.1 Plastics Availability

Plastic scrap is routinely recycled within plastic manufacturing, conversion and fabricating plants, thus minimizing plastic waste from industrial plants.

Specifications (especially for government procurement in the United States) often require the use of virgin plastics for the manufacture of products. When a portion of scrap can be included, an additional 10-20% of the high volume plastics is made available.

Plastic wastes typically are available from urban, industrial and agricultural sectors in a ratio of 100 to 10 to 1. Thus urban refuse represents a potentially good source of plastics. Such plastics, however, are highly contaminated and therefore would probably be substituted for wood products rather than virgin plastics.

4.2 Motives for Recycling

Recycling into plastic fabricated products saves some 85-95 percent of the energy equivalent (both process requirements and feed stock) of an originally produced plastic product. At best, burning a plastic product would recover only 50 percent of the fuel equivalent.

Recycling is often motivated by the potential consequences of not recycling a given product such as banning it from the marketplace. This is especially true where the product can become litter such as with plastic packaging, especially bottles, and become the target of public comment. An option to recycling often favored by legislatures is to force the reuse of products (containers) with a typical result being to decrease the use of plastics (and in the case of bottles, increase the use of glass). This is not necessarily consistent with the conservation of energy or resources when

the cost of retrieving, handling, and sterilization are factored into the life cycle.

A social cost is inherent in the disposal of all wastes and is generally recognized. To the extent that wastes can be reduced and/or a specific material reused or recycled, it will be considered more attractive to society. Government regulations, or the lack of them, reflect the impressions of society (whether correct or not). How people feel about recycling, therefore, is important to its acceptance and promotion.

The widespread use of plastics in throw-away products implies a cheapness which is characterized by a lack of performance. This is in contrast to the fact that plastics are actually highly cost effective--for instance, thin light weight films protect and confine items ranging from nails in small blister packaging to tons of bagged materials on pallets.

4.3 Technologies of Recycling

Recycling of manufacturing scrap (which is inherently free from contaminants) can be done economically with existing technologies provided virgin plastic prices are stable or increasing.

If virgin plastic prices are depressed or decreasing, the margin of profit in recycling decreases to a point where the technologies are not sufficiently efficient to drive added recycling of post-consumer plastics wastes.

To achieve a stable plastics recycling industry, improved technologies that would simplify cleaning or sorting of post-consumer plastic wastes, reduce plastic degradation, and/or desensitize recycled plastics effects on processability are needed.

Processes and products which will accomodate mixed plastic wastes and foreign matter have been available and have achieved some

success, but viable businesses have had trouble existing based on them. Improved processes and chemical additives are desired to make better products at no higher costs.

A variety of sorting systems for municipal refuse are available. These, however, need to be tailored for specific sites since the composition of refuse varies dramatically between, and even within countries. Its mak up varies with season of the year, affluence of the region, customs, etc. Sorting systems which are less dependent on refuse composition are desirable.

Sorting of plastics is usually performed based on physical differences, such as density. Classification of a more specific nature--such as cn chemical composition, selective dissolution or dielectric properties--which can be performed at high speed on small particles could revolutionize recycling.

Stabilization of plastics to reduce degradation upon recycling has not been fully explored. Improving the mechanical properties of recycled plastics would make them more valuable and acceptable.

4.4 Products/Markets for Recycled Plastics

A market exists in all of the NATO countries for clean homogeneous plastic scrap generated by plastic converters and fabricators. Both large industrial plants and independent recyclers are customers for the product with their degree of interest dictated by the relative cost of the equivalent virgin material.

Clean homogeneous plastic scrap is used routinely by plastic converters in combination with virgin materials up to levels of 20 percent except in food packaging applications.

A major portion (>50 percent) of plastics are used in products having an expected life of greater than five years. Those with

a shorter life are the better candidates for recycling and usually are used in packaging.

Markets for plastics from municipal refuse are expected to expand due to an acceptability achieved by successes in the recycling of industrial wastes. As more and more plastic is used, a larger more concentrated supply will be available from municipal refuse which will support a viable recycling industry.

France has set up an integrated recycling program that assures a fixed minimum price for recycled plastics and encourages the development of products made from them. Specifically being addressed is PVC from PVC mineral water bottles which are unique to France.

5. RECOMMENDATIONS

Ten recommendations are made. They are that governments should encourage the development of programs to:

1. Generate and distribute facts pointing out the benefits of recycling plastics, especially as related to the conservation of energy and raw materials and preservation of the environment.

2. Identify and develop specifications and encourage performance standards for recycled plastics so that potential applications can be projected.

3. Provide incentives (such as tax credits) that could be used to promote use of recycled plastics, based on recognition of the social costs of not recycling.

4. Project the future type, amount, and percentage of plastics in the post-consumer waste stream, based on the increasing use of plastics in such industries as, for example, beverage container and automotive.

5. Define appropriate regional approaches to waste plastic collection, sorting (at source and by separation systems) and recycling that might prove viable.

6. Review the status of plastic waste recycling within national solid waste management programs.

7. Determine (through research) bulk plastic identification techniques to contribute to the development of sorting technology and the processing of mixed plastics.

8. Determine (through research) cost effective additives to improve the physical characteristics of recycled plastics.

9. Encourage the development of an international market for recycled and recyclable plastic materials, through such organizations as the Bureau International De La Recuperation.

10. Continue tertiary recycling (such as incineration) of plastics and recovery of the thermal energy for waste management, where primary recycling (recovery of the plastic) is not deemed appropriate.

APPENDIX A

Experts Group Historical Information

APPENDIX A

EXPERTS GROUP
HISTORICAL INFORMATION

I. Identification of Formal Meetings

	Location	Dates	Type Meeting
#1		Mar. 14-15, 1978	CCMS Committee
#2		Jul. 3-4, 1978	Ad Hoc Meeting
#3	Brussels	Sept. 14-15, 1978	Experts Meeting - Draft Proposal
#4	Brussels	Oct. 17-18, 1978	CCMS Plenary
#5	Lisbon	June 27-29, 1979	Experts Meeting - Implementation
#6	The Hague	April 21-23, 1980	Experts Meeting - First Draft, Phase I Report

II. Purpose of Meetings

1. Original proposal to CCMS on "Waste Recovery of PVC"

2. Ad Hoc Meeting to prioritize various proposals. Interest indicated for "Waste Plastic Recovery" with broader scope by France, Italy, UK, Belgium, Canada, Netherlands, FRG, Norway, U.S.

3. Experts convened to put together a generally acceptable proposal with broadened scope to include greater variety of plastics and processes. Municipal, as well as industrial, wastes to be considered. An open-ended meeting which resulted in a concrete proposal.

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4. Experts proposal presented to:

   Plenary of CCMS
   Subject: "Pilot Study on Plastic Wastes"

   CCMS approval requested and obtained by silent consent effective 28 November, 1978 per Joseph M.A.H. Luns, Secretary General of Nato on behalf of the North Atlantic Council

5. Experts meeting to implement study

   Objective - to implement Phase I "Generation of a Data Base"

6. Experts meeting to report on study

   First draft Phase I report reviewed and recommendations defined. Revised Phase I report reviewed by experts individually following meeting.

APPENDIX B

LISTING OF PARTICIPATING EXPERTS

APPENDIX B

LIST OF EXPERTS TO IMPLEMENT NATO-CCMS
PILOT STUDY ON WASTE PLASTIC RECYCLING

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